# Quantification of Littoral Bioluminescence Structure and Induced Water Leaving Radiance

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Grant #: N00014-03-1-0341
http://www.marine.calpoly.edu/researchprograms/auv/

## LONG-TERM GOALS

The long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and spatial variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data over relevant scales will enable better predictability of bioluminescence events in the nearshore coastal ocean.

## OBJECTIVES

There are two primary objectives for this proposal. The first is to initiate time series measurements quantifying the vertical and horizontal structure of bioluminescence off the central coast of California. The second objective is to integrate the time series measurements and a bioluminescence AUV platform into ongoing Navy efforts in other locations along the California coast. This, combined with the forecasting objectives of the observational networks, will also provide a mechanism and framework for predicting bioluminescence potential in the coastal ocean.

## APPROACH

The approach was sequential: first, design and fabricate an optical package with instrumentation to measure inherent optical properties, bioluminescence as well as traditional CTD. Second, design, fabricate and install a profiling unit with the optical package in San Luis Obispo Bay. Third, to develop and deploy the REMUS AUV in various coastal locations in support of existing Navy projects to supplement the bioluminescence/optics capability. Lastly, to explore questions uniquely addressable by using this AUV platform.

## WORK COMPLETED

From January 2003 to September 2003, the majority of the effort has been to modify and upgrade the REMUS AUV for deployment in the Monterey Bay Adaptive Ocean Sampling Network II (AOSN II) experiment. The vehicle was sent to Wood Hole and upgraded with additional Flash memory (1GB) and a new processor to allow for higher frequency data collection with the CTD and ADCP. The sampling frequency of the CDT and ADCP was slower than the bioluminescence sensor, which deceased the data density when merging the datasets for comparative statistics and modeling. In addition, the acoustic navigation system for the vehicle was upgraded from an analog system to digital to increase mission range when in the acoustic network. After two test missions in San Luis Obispo Bay, the REMUS was deployed in nine successive nights as part of AOSN II. Each mission was ~7 hours long and over 45km from Santa Cruz to the MBARI's M1 mooring and back to the coast at a northeast heading for a total distance traveled over the nine days of >400km. In addition to supporting the REMUS operations, we also made sampling measurements from the Pt. Sur for quantification of bioluminescent organisms as well as collected 700 hours of underway ac-9 data for validation of aircraft overflight data as well as particulate/dissolved optical constituent distribution in response to the episodic upwelling event.

Through other programs, instrumentation for the optical package has been obtained for this project. These include: a bioluminescence bathyphotometer, a Wetlabs spectral attenuation/absorption meter (ac-9), a Hobilabs spectral backscatter instrument, and a Seabird SBE-19 CTD. We are in the process of designing the winch system that will profile the optical package. This will be an automated system controllable by a web interface.

This program is also helping to procure a second REMUS vehicle that will serve to spectrally map optical fields, identify phytoplankton groups, and make traditional oceanographic measurements, allowing for spatial validation of remote sensing data, and estimation of leaving radiance from internal light sources. This vehicle is schedule to be delivered in early November 2003.

**RESULTS**

Mission planning developed under past funding allowed for collection of a nine-day time/space data set in Monterey Bay as part of the AOSN II effort (Figure 1). We are presently working on this data set in a number of different areas.

*Significant Spatial Scales of Variability*: We are continuing efforts examining spatial variation. Significant scales are quantified by variogram analysis using residuals of a General Additive Model. We are using this data set to confirm earlier findings that bioluminescence significantly varies on horizontal space scales of ~100 meter inshore (<10km) versus an order of magnitude less offshore (>10km). These results were directly related to the bioluminescent community, with the bioluminescence signals in areas dominated by zooplankton varying on shorter scales. This has significant ramifications for process studies and ecosystem assessment, where these scales (~10m) for sampling are not readily attainable.

*Ecotone Identification*: Data from this effort will continue work to confirm multidimensional relationships between bioluminescence and other physical and biological variables. Hierarchical clustering techniques were used to define unique water masses or water types based on temperature, salinity, density, fluorescence and optical backscatter. Subsequent water masses were then examined using Generalized Least Squares ANOVA to determine if the bioluminescence in those water types was different. Results were highly significant ($p<<0.001$) and demonstrated that clustering techniques were successful in defining unique water masses. Repetitive temporal sampling of particular areas (i.e. Monterey Bay) allows for ecotone classification (with specific bioluminescence signatures) for testable prediction.

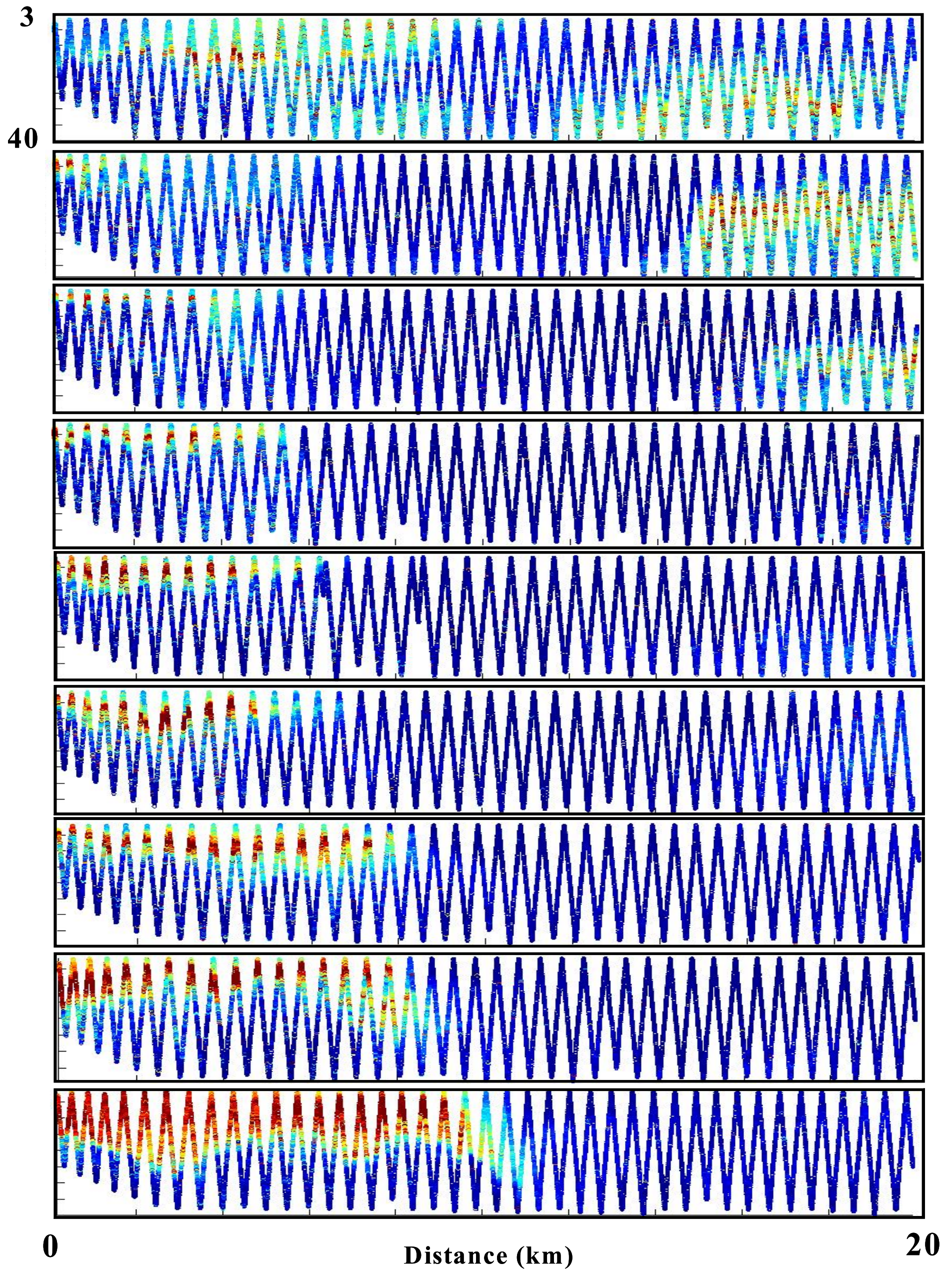


***Figure 1. Time series of the depth distribution of bioluminescence along a 20km north-south transect in Monterey Bay. Each panel represents a night starting with 10-Aug, 2003(top). Bioluminescence ranges on a log scale from 1e8-2e11 photons/sec/L.***

*Modeling Efforts for Particle Trajectories*: Repetitive time series of spatial data from Monterey Bay is also being used to further validate an early Lagrangian model run (Shulman 2003), testing the ability to predict bioluminescence as passive particles. Data from the REMUS provides true time series testing of particle trajectories as outputted from the ICON model. The vehicle in 2003 was deployed along two transect lines each night, one which can now be used to validate the other. Data has been sent to NRL Stennis (I. Shulman) for assimilation.

*Bioluminescence as a Tool for Discriminating Trophic Structure*: As bioluminescent organisms differ with respect to bioluminescent flash intensity and duration, signals measured by the bioluminescence bathyphotometer were used to discriminate between zooplankton (higher flash signal) and phytoplankton (lower background signal). By examining the variance in bioluminescence as a function of the intensity of the signal, we have shown that this is a new approach to effectively separate out phytoplankton from zooplankton and has significance as an effective tool for rapid assessment of distribution as well as validation of ecosystem modeling output. We are using the AOSN II data set to test the robustness of this relationship as a function of time and place.

## IMPACT/APPLICATION

This project is helping to provide relevant scales of temporal and spatial scales of change and has developed an effective approach to separating out trophic structure in the coastal environment, both vital for ecosystem model parameterization and validation. This project also integrated bioluminescence measurements with optics, making it possible to quantify bioluminescence leaving radiance on relevant scales.

## TRANSITIONS

Fine-scale vertical bioluminescent measurements off the coasts of New Jersey and California have improved the ability to predict bioluminescence events in the near shore littoral regions of the marine environment. The addition of the optical REMUS and optical profiling package will help quantify the leaving radiance in the littoral zone.

## RELATED PROJECTS

Ongoing and active collaborations through AOSN II are; N00014-03-1-0208, N00014-03-1-1049, N00014-97-1-0424, N0001403WR20002, N0001403WR20006, N0001403WR20209, N00014-00-1-0842, N00014-03-WX-20882, N00014-03-WR-20009, N000140210853, N0001403WR20063, N00014-02-1-0856, N000140210826, N00014-02-1-0861, N000140310267 , N000140210846, N00014-03-1-0736, N00014-02-1-0846

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Shulman, I., Haddock, S.H.D., McGillicuddy, D.J.Jr., D. Paduan, J.D., Bissett, W.P. (2003). Numerical Modeling of Bioluminescence Distributions in the Coastal Ocean. *Journal of Atmospheric and Oceanic Technology* 20 (7):1060-1068.

## PUBLICATIONS

Moline, M. A., Blackwell, S. M., Allen, B., Austin, T., Forrester, N., Goldsborogh, R., Purcell, M., Stokey, R. and C. von Alt. Remote Environmental Monitoring UnitS: An Autonomous Vehicle for Characterizing Coastal Environments. *J. Atmos. Oceanic. Technol*. [submitted, refereed]

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